

LA-UR-16-20790

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Title: (Mis)Understanding Radiation

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Intended for: Presentation

Issued: 2016-02-10

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(Mis)Understanding Radiation

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February 2016

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Objective

“The trouble with people is not that they don’t know, but that they know so much that ain’t so.” – Josh Billings 1818-1885

- “Common Knowledge” about radiation is that all radiation is dangerous and its danger is cumulative
- High levels of radiation unquestionably cause death, sickness, and an increased risk of cancer
- Low levels of radiation are not harmful to human life and, in fact, humans require additional exposure to ionizing radiation in order to achieve optimum health via a process known as **Radiation Hormesis**

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Radiation: Fears vs Reality

We all **“know”** that radiation has the ability to cause cancer, the more we are exposed, the more likely we are to develop the disease. We all **“know”** that radiation causes mutations in humans because of its damage to our DNA.

How did we come to **“know”** about radiation and to even fear it?

- It is invisible and lacks any kind of “early warning” alerting us to a dangerous presence
- Involuntary risk imposed instead of one willingly accepted
- In the general public there is an almost total lack of knowledge about radiation, how it is measured and its effects at various levels

Bottom line result: all radiation is dangerous, period

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What is the real story?

- Low levels of ionizing radiation are not harmful to human beings or other living creatures as we successfully evolved in such an environment
- Most of us could actually achieve **improved** health and vitality by **increasing** our exposure to radiation
- Multiple studies indicate that the incidence of cancer and other illness is reduced when one is exposed to low levels of radiation
- Society is being denied a virtually unlimited source of clean energy along with medical and public health benefits because of this very reasonable fear of radiation

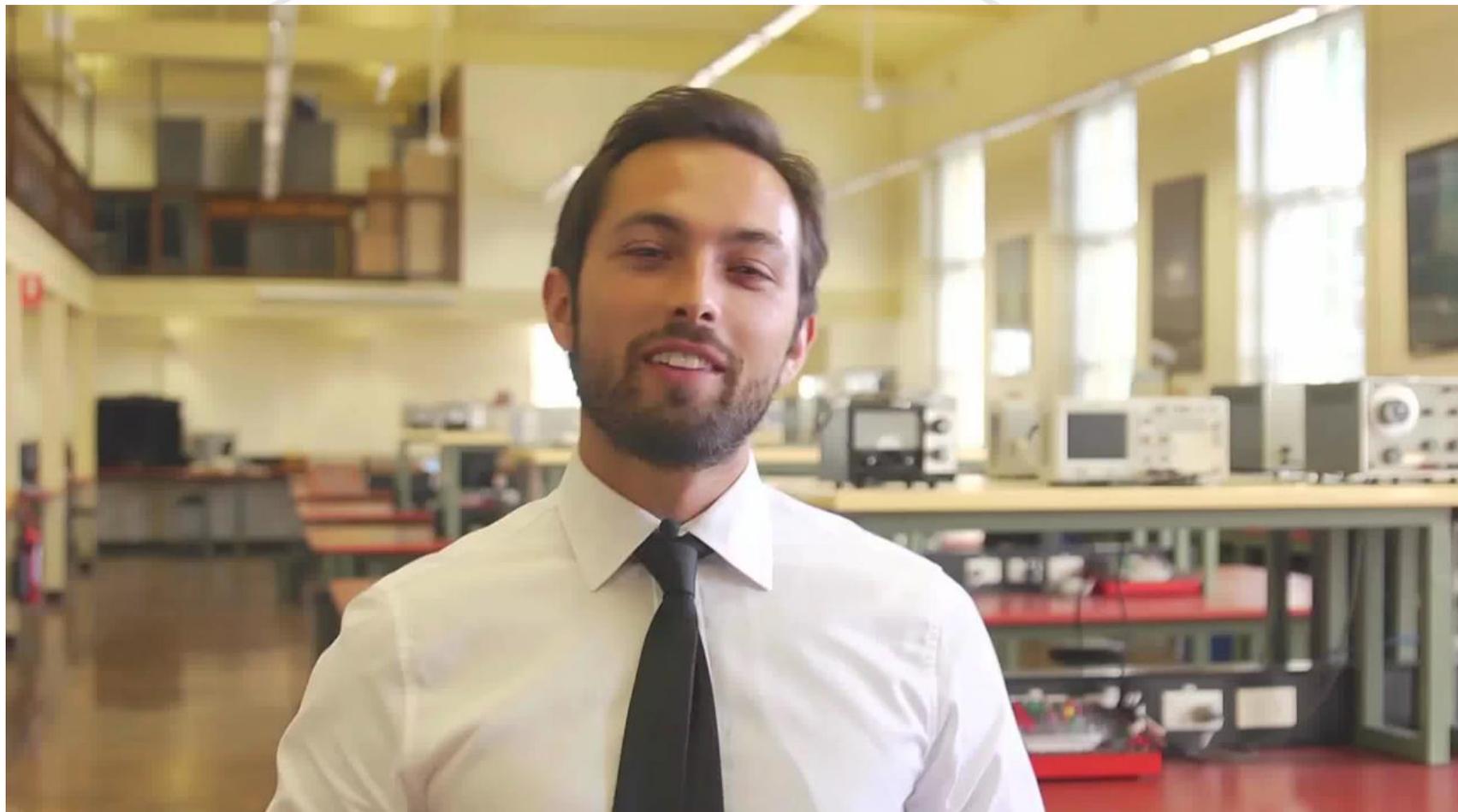
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What is Radiation?

- Veritasium Videos
- Australian Physicist Dr. Derek Muller

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Radiation and Radioactive Atoms



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Atoms and Isotopes



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Types of Radiation



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Radiation Damage



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Three Pillars of Radiation Safety

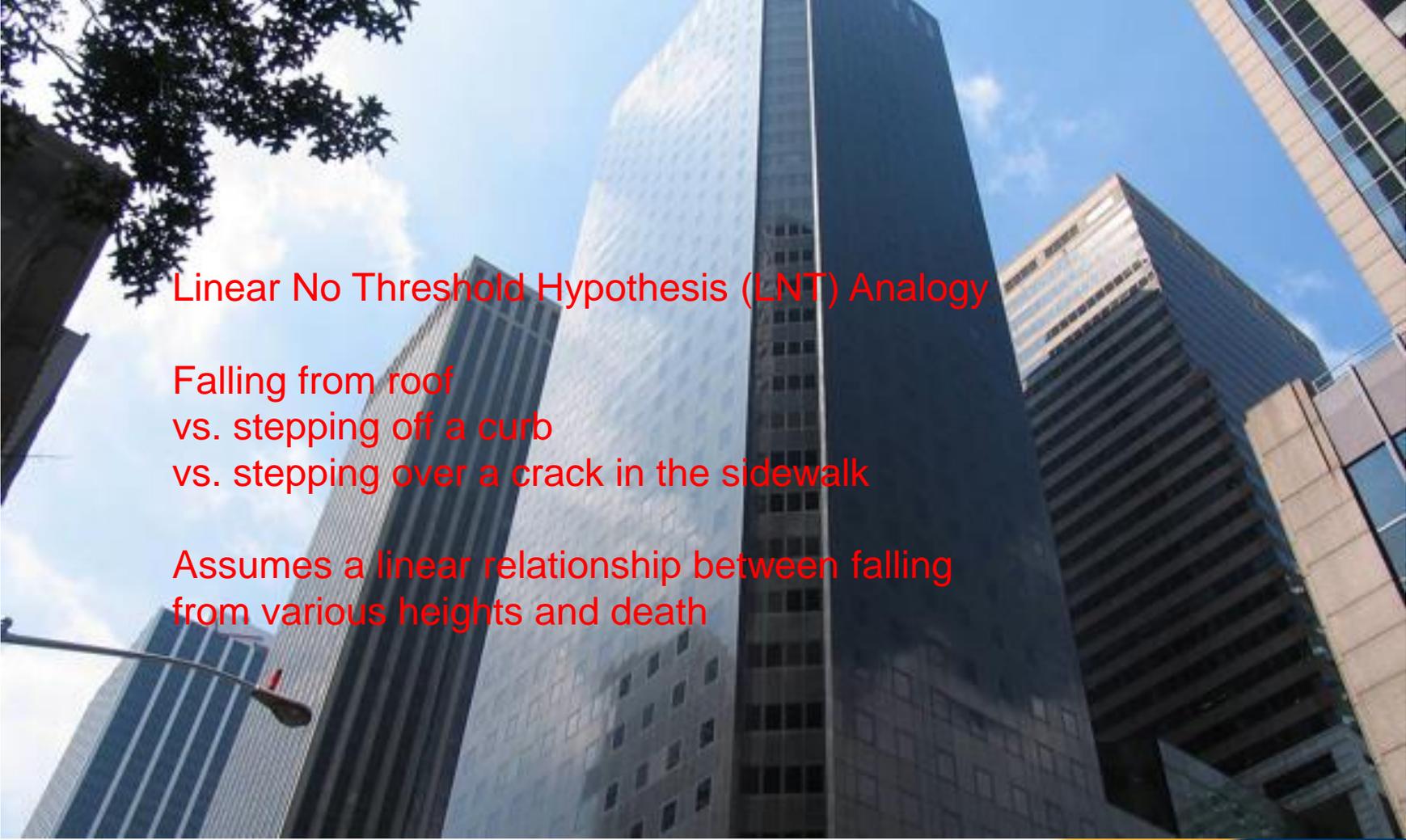
1) Precautionary Principle

- If there are doubts about the safety of a new technology, that technology ought to be severely restricted, if not banned, unless it can be proven to be absolutely safe (proving a negative)
- This presupposes that the consequences of not doing something are potentially catastrophic, while the costs of taking action are negligible; otherwise perform cost/benefit analysis

2) Linear No Threshold (LNT) Hypothesis

3) Collective Dose

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Linear No Threshold Hypothesis (LNT) Analogy

Falling from roof
vs. stepping off a curb
vs. stepping over a crack in the sidewalk

Assumes a linear relationship between falling
from various heights and death

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Collective Dose Analogy

Aspirin doses
1 tablet to 100 people
100 tablets to 1 person

Same collective dose

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Acetylsalicylic acid

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Why not be conservative?

- The Precautionary Principle, the Linear No Threshold Hypothesis and the Collective Dose Hypothesis are all matters that directly affect public policy
- Rules and laws codifying this policy, that all radiation is harmful, are made on the basis of these supposedly scientific but clearly flawed hypotheses
- The result is that significant amounts of finite resources (time, money, and productivity) are expended on lower hazards instead of addressing other higher hazards

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Examples of being conservative

- All radiation of all types tend to be dealt with the same way despite any potential benefits, contrast with chemicals
- Cleanup of sites that handled radioactive materials such as the Rocky Flats Plant (Colorado), Hanford (Washington) and even Los Alamos (New Mexico)
- Radiation workers manage radiation doses using the “As Low As Reasonably Achievable” (ALARA) principle
- Ineffective or even negative responses to radiation releases such as Three Mile Island (Pennsylvania), Chernobyl (Ukraine) and now Fukushima (Japan)

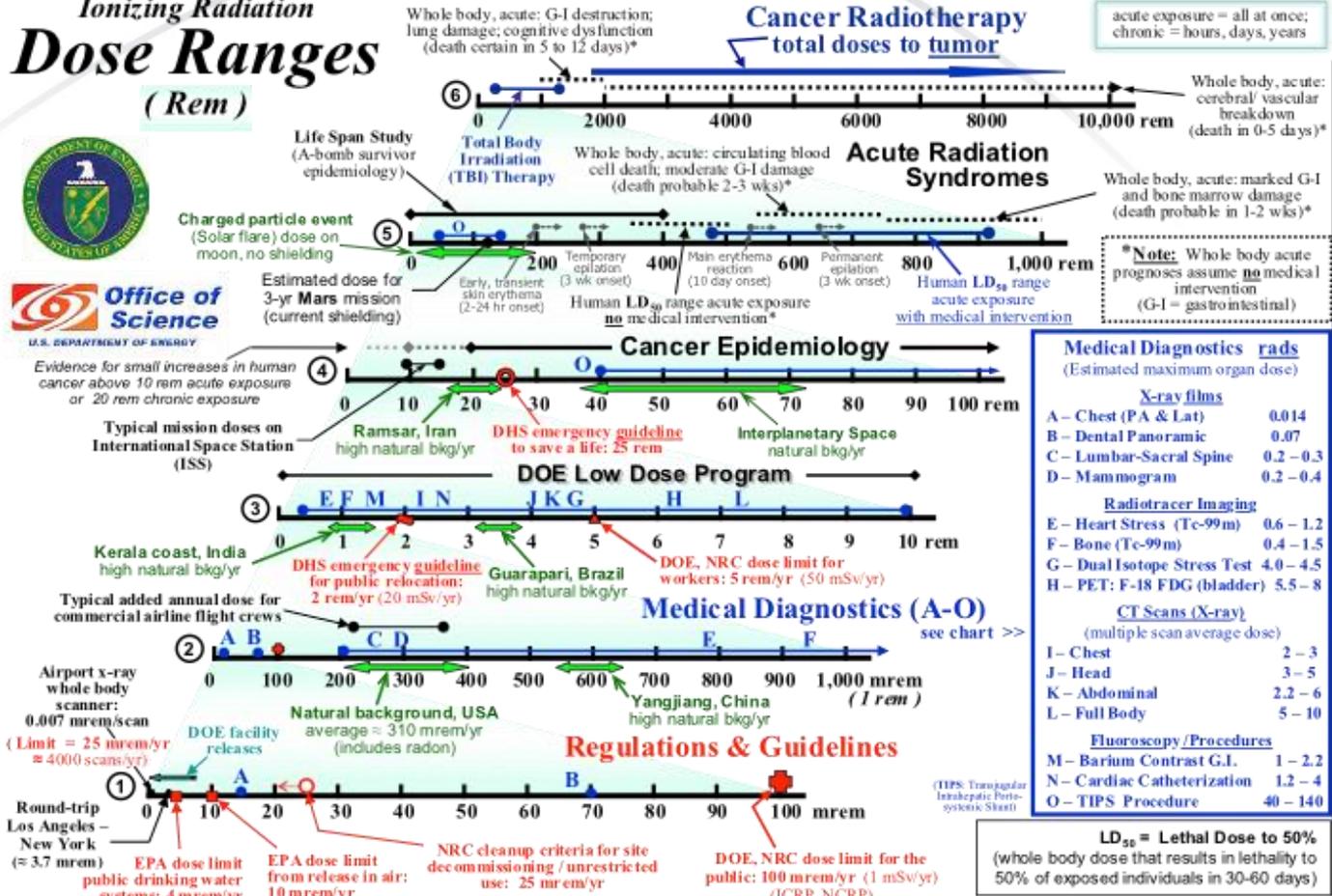
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Sources of Radiation

	% Total
Natural Sources	
Radon	55
Cosmic (doubles for every 6000 ft)	8
Terrestrial	8
Internal	11
Total Natural	82
Man-Made Sources	
Medical X-rays	11
Nuclear Medicine	4
Consumer Goods	3
Nuclear Power	-
Fallout	-
Total Man-Made	18
TOTAL	100

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Ionizing Radiation Dose Ranges (Rem)



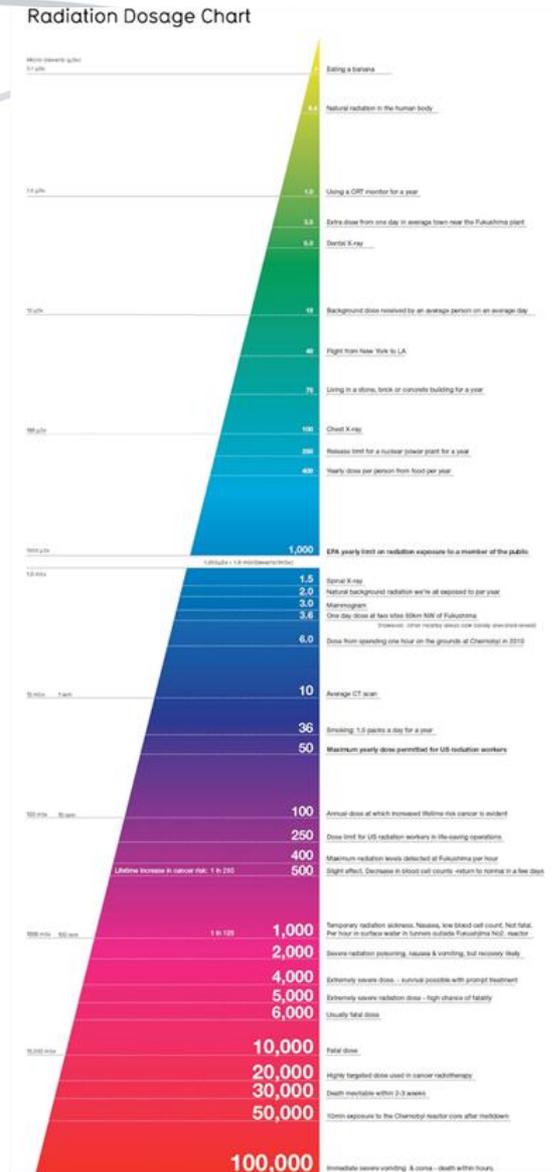
NOTE: This chart was constructed with the intention of providing a simple, user-friendly, "order-of-magnitude" reference for radiation exposures of interest to scientists, managers, and the general public. In that spirit, most quantities are expressed in "dose equivalent" in the more commonly used radiating position units, the rem and Sievert. Medical diagnostics are expressed as estimated maximum organ dose, as they are not in "effective dose" they do not imply an estimation of risk (no tissue weighting). Dose limits are in effective dose, but for most radiation types and energies the difference is numerically not significant within this context. It is acknowledged that the decision to use those units is a simplification, and does not address everyone's needs. (NRC = Nuclear Regulatory Commission; EPA = Environmental Protection Agency; DHS = Department of Homeland Security) Disclaimer: Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information disclosed.

Chart compiled by NF Melting, Office of Science, DOE/BER, "Orders of Magnitude" revised June 2010 1 rem ≈ 1 rad for x- and gamma-rays <http://www.lowdose.energy.gov/>

Source: Office of Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy <http://www.science.doe.gov/ober/>

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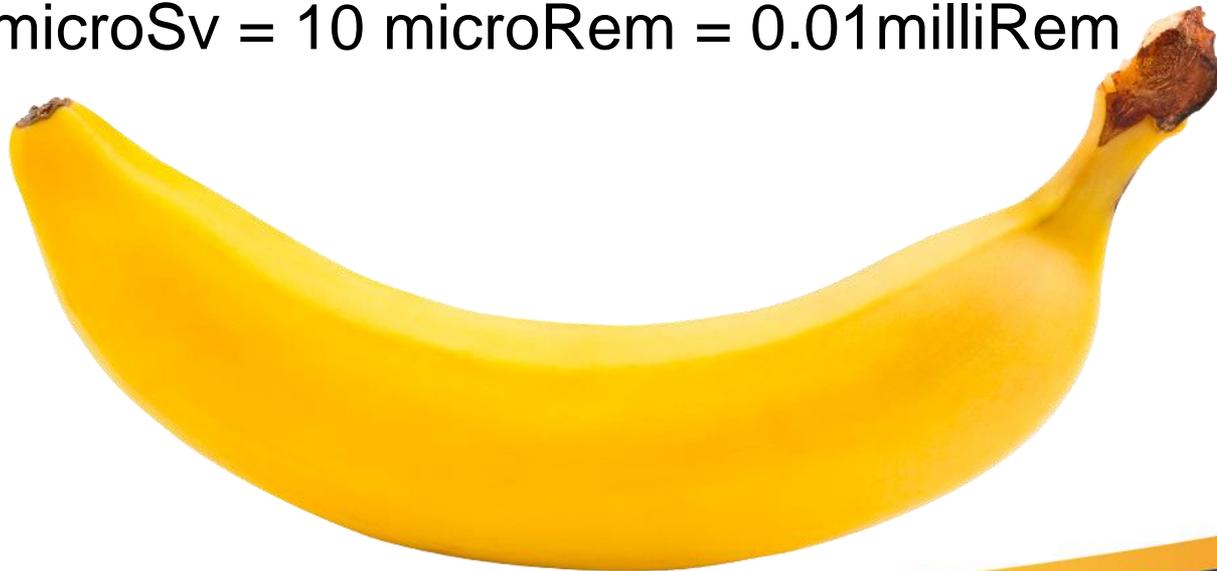




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Radiation Doses

- Office of Science Dose Ranges (Rem or Sv)
- Radiation Dose Chart
- Radiation Dosage Chart (Pyramid)
- Basic unit of radiation set to the K-40 in one banana
~0.1 microSv = 10 microRem = 0.01milliRem



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Most Radioactive Places on Earth

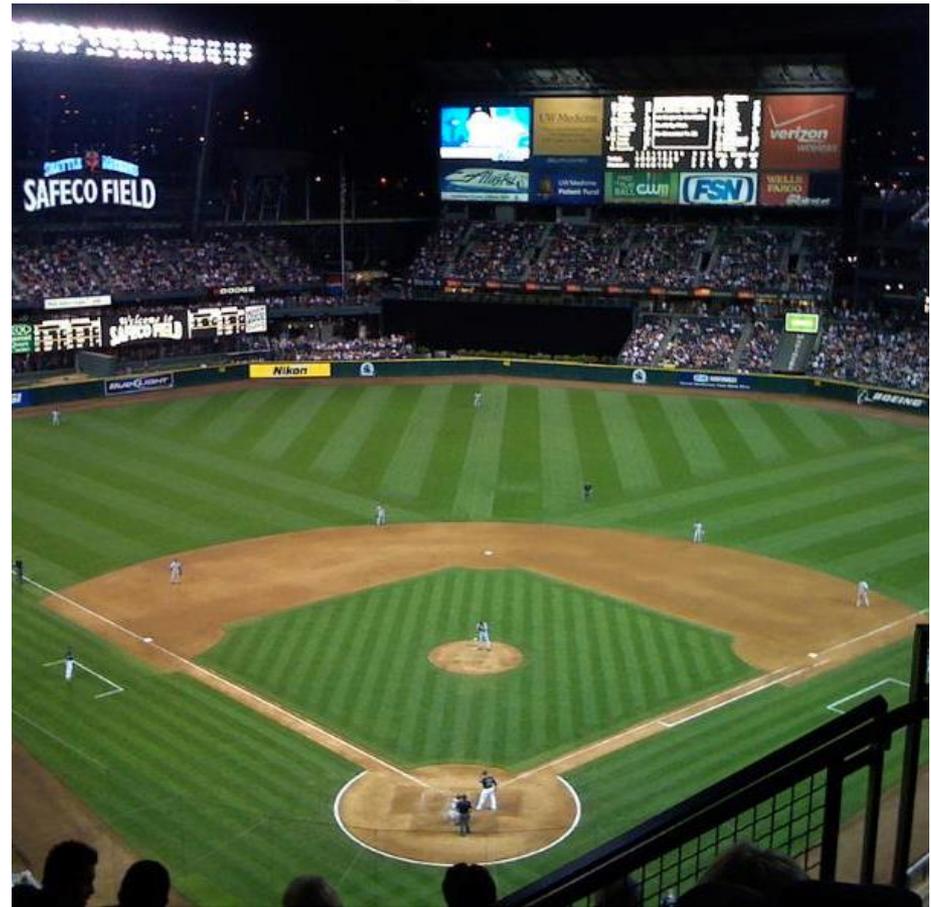
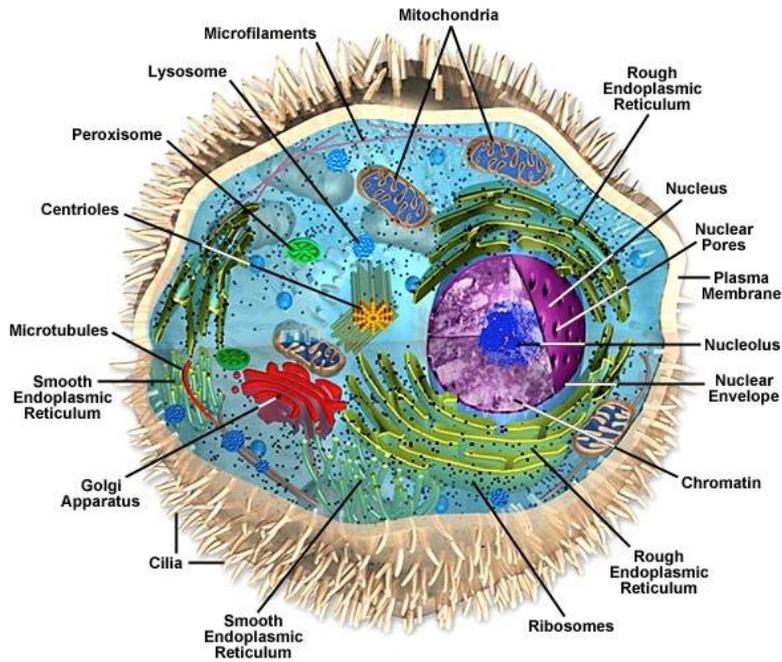
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Human Cells

- “Common Knowledge” is the reason that radiation is a physiological problem in that we assume radioactive particles (specifically ionizing radiation such as alpha, beta and gamma) smash into our cells, break up genes, crush chromosomes and mutilate DNA all causing cells to grow wildly out of control
- In other words, radiation causes **cancer**

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Human Cells



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Human Cells

- 50 – 100 trillion cells in an adult human body (100×10^{12})
- Damage to DNA strands caused by chemical reactions (oxidation, alkylation, hydrolysis) thermal effects, and radiation effects (UV-A, UV-B and ionizing)
- 200,000 DNA repairs every day in every cell with 30,000 unrepaired breaks at any given time.
- Average U.S. citizen exposed to ~1 mRem/day
- Translates to 15,000 radiological “hits” each second, but the odds against any particular event causing cancer in an affected cell is 1 in 30,000,000,000,000,000 (30×10^{15} or 30 quadrillion)

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Human Cells

- Cells respond differently to radiation at high and low doses
- High doses of $>2\text{Sv}$ or $>200\text{Rem}$ or $>200,000\text{mRem}$ results in extensive damage
 - Nuclear bomb blast or a criticality event with associated neutron burst
- Low doses of $<100\text{mSv}$ or $<10\text{Rem}$ or $<10,000\text{mRem}$, particularly if acquired slowly over the course of a year, the body eliminates or repairs the damage by a variety of protective mechanisms that evolved in humans during eons of living in a world bathed in radiation

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LNT Hypothesis

- The LNT hypothesis is used for cancer risk estimation from exposure to ionizing radiation all the way to zero dose based upon a simple linear model extrapolating the effects of high level exposure responses down to low levels
 - Initially all came data from Japanese atomic bomb survivors (assumed that radiation doses could be estimated from bomb's design and their relative location during the acute event)
 - Proven consequences of high doses assumed to apply even near zero dose
 - No threshold below which radiation is harmless, hence LNT predicts some rate or frequency of cancer at all doses

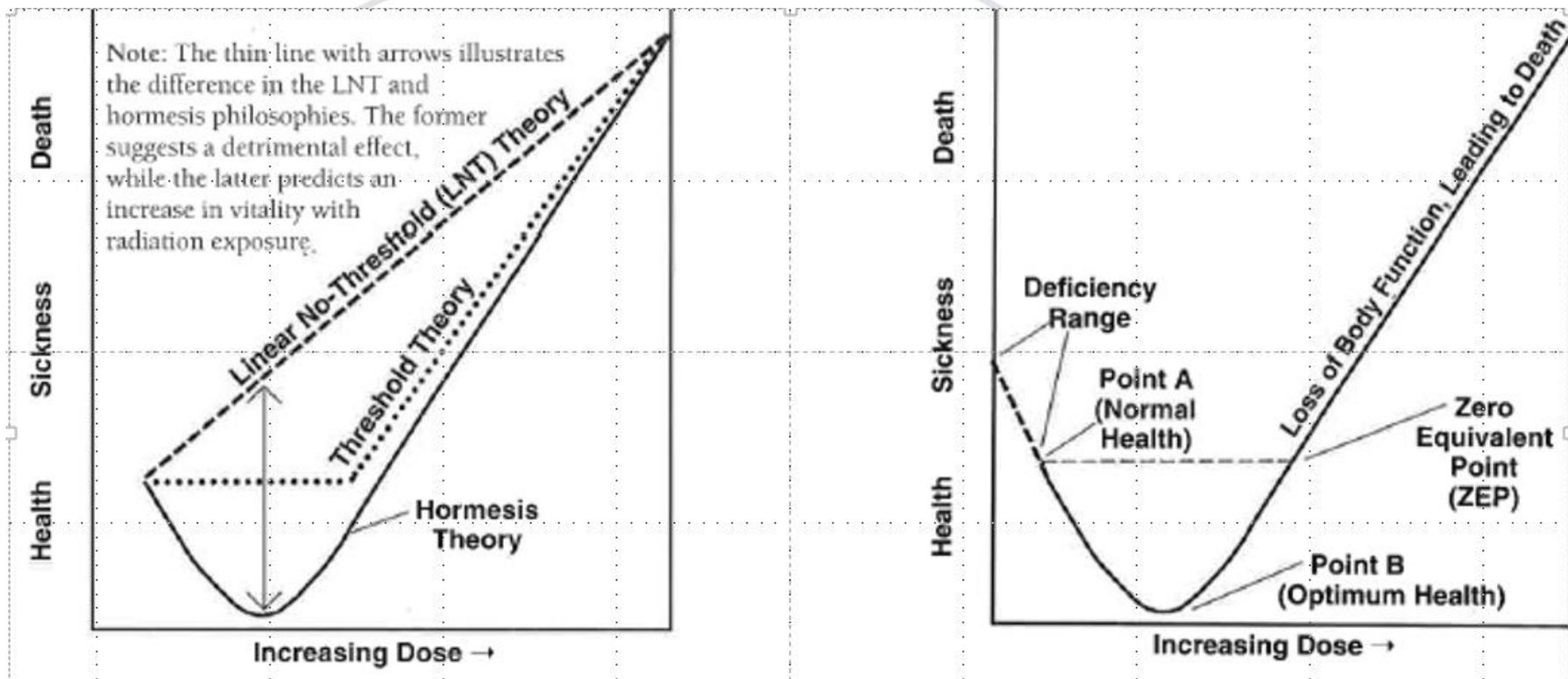
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LNT Data

- The LNT hypothesis is based upon a simple model extrapolating the effects of high level exposure responses down to low levels
- When low level data are available they show a stimulatory or positive biological response known as **hormesis**
 - Hiroshima and Nagasaki atomic bombing survivors from 1945
 - Taiwan radioactive Co-60 mixed with structural steel used in apartments, exposed 10,000 residents for 9 - 20 years (1983 – 2003) doses that averaged 40,000 mRem
 - U.S. shipyard workers (1957 -1967) study for DOE in 1980's of ~43,000 cohorts exposed to occupational doses <5,000 mRem/year from Co-60 activated steel
 - Cs-137 fallout in reindeer herders in arctic Norway (1950-2010)
 - Nuclear Weapons Complex worker health data (ongoing)

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Dose Response Theories



- “The dose makes the poison.”
- Similar responses for vitamins and trace minerals (vitamin C for preventing scurvy in the Royal Navy, table salt, etc.)

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LNT x Collective Dose

Phantom predicted cancer induced deaths are estimated by applying the LNT model to a large population after nuclear reactor incidents release measurable amount of radioactive material into the general environment

- Three Mile Island
- Chernobyl
- Fukushima Daiichi

Often the responses (evacuations, fear induced stress, proactive abortions) are more harmful than the actual exposure to radiation

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LNT x Collective Dose

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2013 Annual Report

*In general, increases in the incidence of health effects in populations cannot be attributed reliably to chronic exposure to radiation at levels that are typical of the global average background levels of radiation. This is because of the uncertainties associated with the assessment of risks at low doses, the current absence of radiation-specific biomarkers for health effects and the insufficient statistical power of epidemiological studies. Therefore, the Scientific Committee **does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels.***

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Plutonium

- “The most toxic substance known to Man”
- Toxicity studies show the element to be about as toxic as caffeine and about 1/1,000,000,000,000 (10^{-12}) the toxicity of botulism toxin.
- Concern is about getting the radioactive material inside the body either by inhalation, ingestion or through an open wound where organs would be continually irradiated in an **uncontrolled** way.

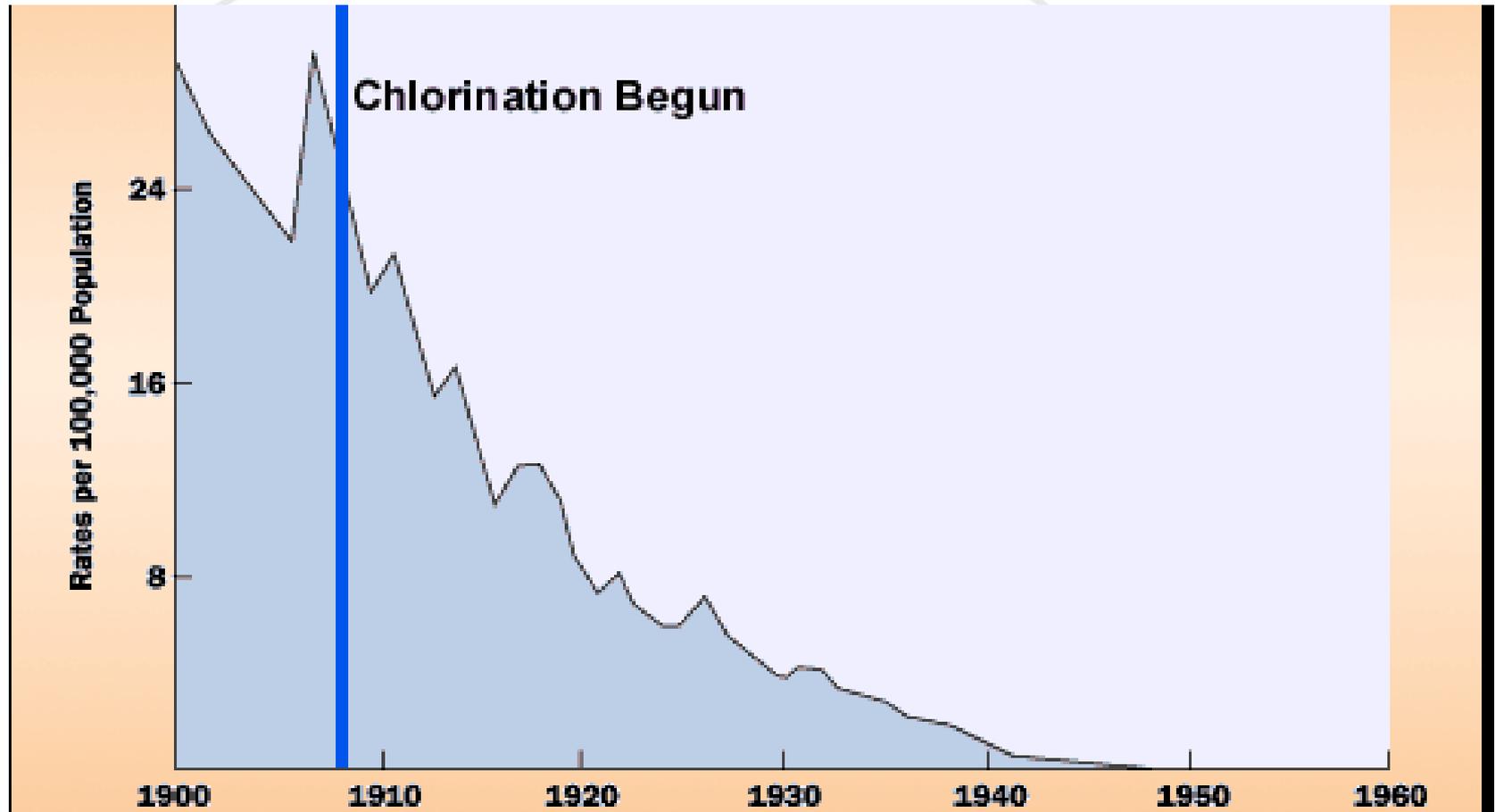
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Public Health Analogy

- In the 1800's as a result of the Industrial Revolution populations migrated into urban areas (cities) resulting in new Public Health issues with diseases that swept through killing tens of thousands
- “Common Knowledge” was that urban diseases such a cholera or typhoid were transmitted by “miasma” or poisonous, foul-smelling airs generated by the lack of sanitary sewers (people and animals)
- Germ theory (Pasteur) established the link between dirt and disease, thus such diseases were actually transmitted by contaminated drinking water supplies
 - Medical doctors washing their hands before treating patients
 - Sanitation of cities including removal of refuse and sewage along with a supply of clean water
- Modern chemical treatment with chlorine of water supplies began in the U.S. in Jersey City by 1908 (Leal) making drinking water “pure and wholesome” for human consumption

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Public Health Analogy



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Time to Revisit Radiation

- Recent mainstream media reports and articles
 - November 2015 – Peter Thiel in the *New York Times* “The New Atomic Age We Need”
 - December 2015 – Holman Jenkins in the *Wall Street Journal* “U.S. Regulators May Radically Revise Safety Assumptions About Atomic Radiation”
 - Fall 2015 – Seigel and Pennington in *Skeptic Magazine* “The Mismeasure of Radiation”

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Potential Positive Impacts

- Once we overcome the apprehension and fear of low level radiation many, many nuclear opportunities are already present
 - Improved medical diagnostics (NMRI or CAT scans) and myriad new treatments for cancer
 - Food irradiation to eliminate bacterial contamination (E-coli)
 - Radiation hormesis for improved human health and vitality
 - Improved nuclear reactor designs (Generations III or IV) based upon either U-Pu or Th-U fuel cycles with significantly reduced construction, operation and waste disposal costs, improved safety, and dramatically reduced CO₂ emissions

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Pandora's Promise



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Conclusions

“Engineers were put on Earth to attempt the conversion of scientists’ ideas into something normal people can fathom.” – Ed Hiserodt

- Much like the introduction of chemicals into society of 100 years ago, we are poised to change the way society deals with radioactive materials and radiation
- First step is to achieve a better understanding of radiation, both the negative as well as the positive effects

QUESTIONS or COMMENTS?

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Specific Case - EEOICPA

Energy Employees Occupational Illness Compensation Program Act established in 2000 to “compensate current or former employees of the DOE who were diagnosed with a radiogenic cancer as a result of exposure to radiation.”

- Everybody dies of something, eventually
- As the Public Health and Health Care systems improve, the incidence of cancer which tends to impact those later in life becomes a larger cause of death (~1/3 of the general population)
- The high “background” of cancer in the population confounds epidemiological studies to determine statistically significant cause and effect relationships between exposure to radiation and the incidence of cancer
- U.S. Department of Labor implements the program, initially used the “special exposure cohort” method of resolving claims, but since 2004 benefits are no longer tied to causal effects but only to employment history
- McClatchyDC published Irradiated report (2015) suggesting over 30,000 nuclear workers at weapons facilities across the U.S. have died from work related cancer

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Local Impacts

- Impacts on As Low As Reasonably Achievable (ALARA) approach to radiation dose management
- Committed Effective Dose Equivalent (CEDE) internal uptake model and chelation
- Impacts of forced relocation on populations due to low level radiation releases (one possible result of the Cerro Grande Fire in 2000 on Los Alamos and surrounding counties)

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